



Final Report



Rail Emission Model



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Executive summary

For this study, updated emission factors for rail vehicles and road vehicles have been compiled for CO₂, SO₂, NO_x, PM₁₀, CO and VOCs. The emission factors have been incorporated into a simple spreadsheet which allows estimation of net emissions from changes to rail services, including emissions from displaced road transport.

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Introduction

The major environmental issues facing the rail industry include emissions of greenhouse gases and pollutants affecting air quality. This study builds on and updates the information provided in the SRA's Environmental Agenda (AEA Technology Environment, 2001) on pollutant and CO₂ emissions from the railway industry and on new rolling stock. In addition, updated emission factors, consistent with updates from DEFRA for road traffic, are presented to allow a comparison to be made between the two modes of transport. A simple spreadsheet model has been constructed to allow rail emissions to be compared to displaced road emissions, so that the net impact of a rail development scheme can be estimated.

The main tasks were:

- To review the emission factors (diesel and electric stock) at present used for rail.
- For each stock type to provide a list of emission factors for the years 2000, 2005, 2010 for CO₂, PM₁₀, CO, NO_x, SO₂ & VOCs by vehicle and / or train kilometre.
- For both diesel and petrol based road vehicles to provide emission factors for the years 2000, 2005 & 2010 for CO₂, PM₁₀, CO, NO_x, SO₂ & VOCs.
- To produce guidance on the application of these emission factors to changes in train services up to and including the year 2020.
- To provide guidance on the estimation of emissions from fixed sources such as stations and depots.
- To produce an EXCEL compatible spreadsheet with which the SRA can calculate the net impact on emissions of service changes based on the following inputs
 - Increase in train kilometres by stock type
 - Reduction in road vehicle km by vehicle type
 - Change in average road vehicle speed.

Environmental impacts

Emissions from the rail industry can be divided into three types. There are those from diesel trains, those that are produced indirectly from electric trains and those from stationary sources, for example at stations. Diesel trains directly emit all of the pollutants associated with fuel combustion (see below). These pollutants will also be emitted indirectly from electric trains via electricity generation in power plants. Finally, stationary sources include the combustion of burning oil and natural gas in stations and depots.

This report considers the main fuel combustion emissions. These include the main greenhouse gas, carbon dioxide (CO₂), and the air quality pollutants sulphur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), volatile organic compounds (VOCs) and particulates (PM₁₀). A brief description of each pollutant and their effects on human health and the environment are provided below.

Carbon dioxide

The potential effects of global climate change from greenhouse gas emissions are diverse and very large.. The major greenhouse gases are carbon dioxide, methane and nitrous oxide. The major source of greenhouse gas emissions from the rail industry is carbon dioxide (CO₂) from fuel combustion, either from stationary sources, diesel trains or from electricity generation for traction.

Sulphur dioxide

Sulphur dioxide (SO₂) is an acidic gas which combines with water vapour in the atmosphere to produce acid rain. Both wet and dry deposition have been implicated in the damage and destruction of vegetation and in the degradation of soils, building materials and watercourses. SO₂ in ambient air can also affect human health, particularly in those suffering from asthma and chronic lung diseases.

The principal source of this gas is power stations burning fossil fuels which contain sulphur. SO₂ emissions have reduced dramatically over the last decade as a result of the move away from coal in power generation, and from reductions in the sulphur content of all solid and liquid fuel.

Both the Air Quality Strategy and the EU 1st Daughter Directive (1999/30/EEC) contain limit values for ambient concentrations of sulphur dioxide.

SO₂ emissions will arise from diesel trains and stationary sources from the direct combustion of fossil fuels, and indirectly from power station emissions associated with electric generation for traction.

Nitrogen dioxide

Nitrogen oxides are formed during high temperature combustion processes from the oxidation of nitrogen in the air or fuel. The principal source of nitrogen oxides - nitric oxide (NO) and nitrogen dioxide (NO₂), collectively known as NO_x - is road traffic, which is responsible for approximately half the emissions. NO and NO₂ concentrations are therefore greatest in urban areas where traffic is heaviest. Other important sources are power stations, heating plants and industrial processes.

Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infections such as influenza. Continued or frequent exposure to concentrations that are typically much higher than those normally found in the ambient air may cause increased incidence of acute respiratory illness in children.

NO_x emissions will arise from diesel trains and stationary sources from the direct combustion of fossil fuels, and indirectly from power station emissions associated with electric generation for traction.

Carbon monoxide

Carbon monoxide (CO) is a toxic gas which is emitted into the atmosphere as a result of combustion processes, and is also formed by the oxidation of hydrocarbons and other organic compounds. In European urban areas, CO is produced almost entirely (90%) from road traffic emissions.

This gas prevents the normal transport of oxygen by the blood. This can lead to a

significant reduction in the supply of oxygen to the heart, particularly in people suffering from heart disease.

CO emissions will arise from diesel trains and stationary sources from the direct combustion of fossil fuels, and indirectly from power station emissions associated with electric generation for traction.

Volatile organic compounds

VOCs are released in vehicle exhaust gases either as unburned fuels or as combustion products, and are also emitted by the evaporation of solvents and motor fuels.

Benzene is a VOC which is a minor constituent of petrol. The main sources of benzene in the atmosphere in Europe are the distribution and combustion of petrol. Of these, combustion by petrol vehicles is the single biggest source (70% of total emissions).

1,3-butadiene, like benzene, is a VOC emitted into the atmosphere principally from fuel combustion of petrol and diesel vehicles. 1,3-butadiene is also an important chemical in certain industrial processes, particularly the manufacture of synthetic rubber.

Possible chronic health effects include cancer, central nervous system disorders, liver and kidney damage, reproductive disorders, and birth defects

Emissions will arise from diesel trains and stationary sources from the direct combustion of fossil fuels, and indirectly from power station emissions associated with electric generation for traction.

Particulates

Airborne particulate matter varies widely in its physical and chemical composition, source and particle size. PM₁₀ particles (the fraction of particulates in air of very small size (<10 µm)) are of major current concern, as they are small enough to penetrate deep into the lungs and so potentially pose significant health risks. The principal source of airborne PM₁₀ matter in European cities is road traffic emissions, particularly from diesel vehicles.

Fine particles are associated with a number of health effects, notably acute mortality (deaths brought forward) and chronic mortality (life expectancy), as well as a number of other severe health endpoints such as hospital admissions. They are currently the major pollutant of concern with respect to the health based evidence.

Emissions will arise from diesel trains and stationary sources from the direct combustion of fossil fuels, and indirectly from power station emissions associated with electric generation for traction.

Relevant legislation

Emissions from road and rail transport will be affected by current and forthcoming legislation. Below we review the main legislation of relevance to road and rail transport over the next 20 years.

Legislation governing GHG emissions

Two commitments have been made by the UK to reduce emissions of greenhouse gases.

- Firstly there is a legally binding target from **Kyoto** to reduce emissions of a basket of six greenhouse gases (carbon dioxide, methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons and sulphur hexafluoride). The target is to achieve a reduction of the global warming potential of the six greenhouse gases of 12.5% by 2008 - 2012 (based on 1990 emission estimates). The global warming potential is a measure of the effectiveness in global warming relative to carbon dioxide over a 100 year time horizon.
- Secondly, the UK has its own **domestic goal** of reducing CO₂ emissions to 20% below 1990 levels by 2010.

In order to achieve these targets, the **UK Climate Change Strategy** was formulated in 2000. The main aim of the strategy is to reduce greenhouse gas emissions. A programme of integrated policies and measures including initiatives for business, domestic and transport sectors has been set up. Studies have shown that the proposals in the programme could reduce the UK's greenhouse gas emissions to 23% below 1990 levels in 2010 and CO₂ emissions to 19% below 1990 levels in 2010 (DETR, 2000). The UK is therefore on track to hit its Kyoto commitment, but to narrowly miss its domestic target.

However, studies have shown that much larger reductions will be needed to avoid climate change. The Royal Commission on Environmental Pollution suggested in its 2000 report¹ that the UK needs to reduce its emissions (from 2000 levels) by 60% by 2050. These longer term targets are extremely challenging and would require major changes in energy use and carriers.

Legislation governing air quality

There are various environmental standards governing air quality to protect both human health and the environment both at the local level and European / International level.

UK level

During the early 1990s, the Department of Environment, Transport and the Regions (DETR) investigated the need for a new framework for air quality control. This was fuelled by episodes of poor air quality in many of the UK's major urban areas and increasing concerns expressed by both the public and the scientific community. The need to reconcile rising demands in living standards with the maintenance of environmental quality has already been recognised in Agenda 21 and is now taken further with the development of the **Air Quality Strategy (AQS)**. At the centre of the AQS is the use of national air quality standards to enable air quality to be measured and assessed. These also provide the means by which objectives and timescales for the achievement of objectives can be set. Most of the proposed standards have been based on the available information concerning the health effects resulting from different ambient concentrations of selected pollutants and are the consensus view of medical experts on the Expert Panel on Air Quality Standards (EPAQS). Where standards / objectives are not predicted to be met the local authority must declare an air quality management area (AQMA).

¹ Royal Commission on Environmental Pollution (2000) *Twenty-Second report: Energy - the changing climate*. HMSO, Norwich, United Kingdom.

The 'Air Quality Strategy' sets objective levels for eight regulated pollutants in the UK to be met by 2005. These objectives include both annual and short-term (24 hour, 1 hour and 15 minute) objectives. Local authorities have completed an assessment of whether these objectives will be met across the entire UK. The most challenging of these targets are for the pollutants NO₂ and PM₁₀.

Note, the Local Air Quality is not a problem for the rail industry. The levels of emissions along railway lines do not lead to exceedances of the NAQS objectives. The only areas where the NAQS may be of concern are possibly major termini with receptors (houses) close by.

European level

Similar to the UK Air Quality Strategy, the EU Directive (96/62/EC) on Ambient Air Quality Assessment and Management establishes a framework under which the EU can set limit values or target values for concentrations of specified pollutants in ambient air. The Directive identifies 12 pollutants for which limit or target values will be set in subsequent daughter directives. Directive 1999/30/EC (1st Air Quality Daughter Directive) establishes legally binding limit values for SO₂, NO₂, particles and lead. These values are to be achieved by 1 January 2005 and 2010. The Directive was adopted in April 1999 and entered into force in 1999. Member states were required to implement it by July 2001. The target levels are identical or slightly less severe than the UK AQS objectives above.

Additional European Directives that influence emissions from the rail industry and road transport include the Auto oil programme, the Large Combustion Plant Directive, Integrated Pollution Prevention Control and the Sulphur Content of Liquid Fuels directive (SCLF). These are briefly outlined below:

The **Auto-Oil** programme has brought together the oil and automotive industries and the European Commission to agree tighter fuel specifications to reduce greenhouse gases and other pollutants.

The **Sulphur Content of Liquid Fuels Directive** (1999/32/EC) was implemented in the UK by regulations that came into force on 27 June 2000. This limited the sulphur content of gas oil to 0.2 per cent from 1 July 2000 and to 0.1 per cent from 1 January 2008. Similarly, heavy fuel oil sulphur content will be limited to 1 per cent from 1 January 2003 as compared to a current specification of 3.5 per cent, with the option of having a limit on total sulphur dioxide emissions rather than fuel sulphur. Reducing sulphur levels in liquid fuels will also influence particulate emissions but at the present time it is unsure to what extent.

The **Revised Large Combustion Plants Directive** (LCPD, 2001/80/EC) applies to combustion plants with a thermal output of greater than 50 MW. The LCPD aims to reduce acidification, ground level ozone and particles throughout Europe by controlling emissions of sulphur dioxide (SO₂), nitrogen oxides (NO_x) and dust (particulate matter (PM)) from large combustion plants (LCPs). These include plants in power stations, petroleum refineries, steelworks and other industrial processes running on solid, liquid or gaseous fuel.

The **IPPC Directive** (EC/61/96) is being introduced across Europe to improve the standard of environmental protection. The purpose of the Directive is to achieve prevention and control of pollution arising from a range of activities. It lays down measures designed to prevent, or where that is not practicable, to reduce emissions to air, land and water from these activities.

These European Directives will affect emissions from the rail industry.

- The directives will impact on large stationary sources, specifically power stations over the next few years. Emissions from large-scale electricity generation plants will fall over the next 10 years in the UK leading to much lower emissions for electric traction.
- The Sulphur Content Of Certain Liquid Fuels Directive sets maximum levels for the sulphur content of gas oil of 0.1% from 2008. This will lower emissions of SO₂ and PM₁₀ from diesel trains.
- The auto-oil programme will lead to tighter emissions standards for cars and goods vehicles which will further lower emissions from the road sector. It also sets tighter fuel quality specifications which apply to all petrol and diesel sold. This will lead to very large reductions in the emissions from road vehicles and will affect the relative environmental performance of rail over road.

Legislation governing emissions from road transport & the rail industry

Road transport emissions are predicted to decline in future years as a result of European Directives on vehicle emissions and fuel quality and the implementation of the Government's **Ten Year Transport Plan**. Increasing rail transport is one of the main options in the Government's Ten Year Plan.

Emissions from the rail sector in the future will depend on the fuel efficiency of the diesel train fleet and the electricity mix. In 1995 the European Union proposed the first European Legislation to regulate emissions from off road mobile equipment (Directive 97/68/EEC). However, engines used in ships, railway locomotives and aircraft are not covered by the standard. At present there are no Directives or Regulations governing emissions from diesel rolling stock.

Both passenger kilometres and freight kilometres have increased since 1990.

Table 1. Passenger kilometres and freight moved on national railways

	90/91	91/92	92/93	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01	01/02
Passenger km (billion km)	33.2	32.5	31.7	30.4	28.7	30	32.1	34.7	36.3	38.5	38.2	39.1
Freight moved (billion tonne km)	16	15.3	15.5	13.8	13	13.3	15.1	16.9	17.3	18.2	18.1	19.7

Source: SRA, National Rail Trends, 2002

Comparison of emissions from road and rail

Energy consumption by the railway industry of oil, gas oil and electricity is provided in the Digest of United Kingdom Energy Statistics (DUKES) produced by the Department of Trade and Industry (DTI).

Table 2. Energy consumption by the railway industry

	1999	2000	2001
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Burning oil (thousand tonnes)	12	12	12
Gas oil (thousand tonnes)	451	429	405
Electricity for traction (Gwh)	2,700	2,700	2,700

Source: DTI DUKES 2002

The United Kingdom National Atmospheric Emissions Inventory (NAEI) provides estimates of pollutant emissions from the rail industry for each year since 1970. The latest emission estimates for 2000 are provided in Tables 3 and 4, including an estimate of indirect emissions from electricity consumption for traction. Note there will also be a contribution from electricity consumption in railway buildings, but this is not identified separately in DUKES.

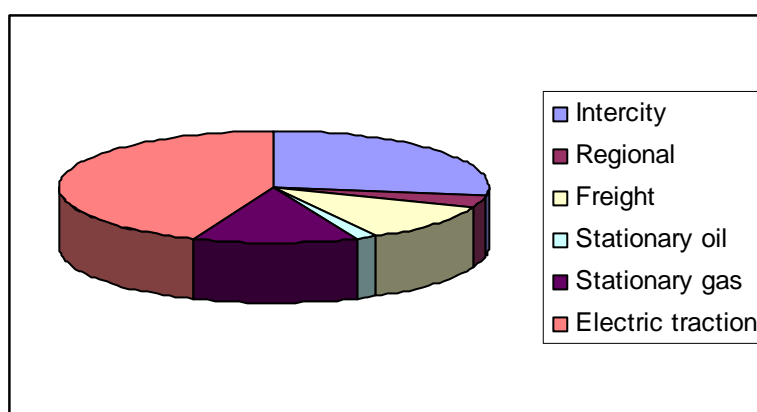
Table 3. Emissions in 2000 of CO₂ from road and rail

	CO ₂ (Mtonnes)
Rail (freight)	0.36
Rail (inter city)	0.88
Rail (regional)	0.12
Rail stationary sources-burning oil	0.04
Rail stationary sources- natural gas	0.40
Rail – electricity for traction	1.41
Total Rail	3.21
Total Road transport emissions	116
Total emissions in 2000	541
% of rail emissions to total	0.59%
% of road emissions to total	21.4%

Source: NAEI

Note: "Regional" and "Intercity" estimates are based on the km travelled in these modes as reported in DETR (1996) Transport Statistics Great Britain. Estimates for later years are extrapolated from the regional / intercity split in 1995, using the LRC emission factors and an assumed mix of train types.

Figure 1: CO₂ emissions from the Rail Industry (Mt), 2000



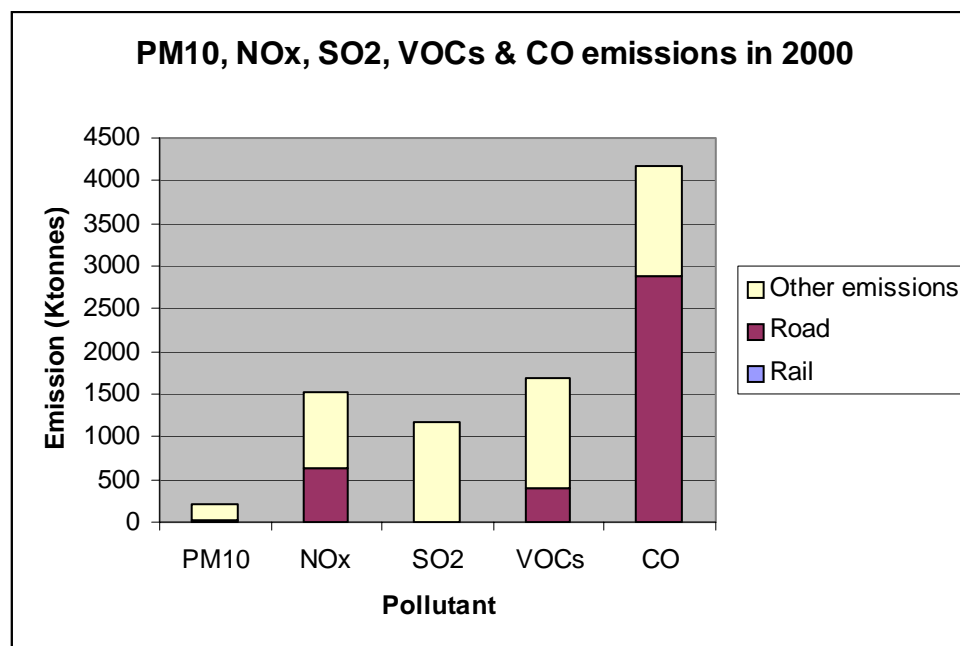
Source: NAEI

Table 4. Emissions in 2000 of PM₁₀, SO₂, NO_x, VOCs & CO from road and rail (Ktonnes).

	PM ₁₀	NO _x	SO ₂	VOCs	CO
Rail (freight)	0.09	2.00	0.30	0.40	0.60
Rail (inter city)	0.63	7.50	0.70	1.04	2.20
Rail (regional)	0.01	1.60	0.10	0.04	0.30
Rail stationary sources-burning oil	0.00	0.03	0.01	0.00	0.00
Rail stationary sources-natural gas	0.00	0.70	0.00	0.03	0.02
Rail - electric traction	0.20	3.28	7.57	0.07	0.55
Total Rail	0.93	15.11	8.68	1.58	3.67
Total Road transport emissions	31	629	5.9	408	2881
Total emissions in 2000	172	1512	1165	1676	4167
% of rail emissions to total	0.54%	1.00%	0.74%	0.09%	0.09%
% of road emissions to total	18%	42%	1%	24%	69%

Source: NAEI

Figure 2: Emissions of air pollutants in the UK



For all the six pollutants reported in this study, the contribution to total emissions from rail is less than 1%. The contribution from road transport on the other hand is significant with the sector providing over 20% of CO₂ emissions, 42% of NO_x emissions and 69% of carbon monoxide emissions.

Rail emission factors

This section updates and extends the data provided in the SRA's Environmental Agenda on pollutant emissions in g/km for different train types (AEA Technology Environment, 2001). This study has refined estimates of electricity and diesel consumption by trains. The analysis has also set out to derive new data for new train classes such as the Virgin Voyager (class 220/221).

Diesel trains

In general there is little data available on emissions from diesel trains. the major problem is the lack of a consistent set of data, from emission trails for similar test data. Instead, data must be taken from the literature and from the studies available. However, in doing so, care must be taken as fuel consumption and emissions are highly dependent on the type of journey being undertaken – distance, gradients, load, type of track, speed, and distance between stops.

For diesel trains, emission factors have been derived from the following data sources.

1. For class 37, 47, 56, 58, 60, 66 and 67 locomotives and Intercity 125 trains we have used data from an earlier study by the London Research Centre (now absorbed into Transport for London and the Greater London Authority) (LRC, 1998). These include emissions factors for SO₂, PM₁₀, NO_x, VOCs and CO. These emission factors are those currently used in the NAEI. The data for freight trains was originally derived from EWS. The data for passenger trains was derived from BR Research at Derby.
2. For Class 100 diesel multiple units (DMUs) we have used calculated data supplied by AEA Technology Rail, representing fuel consumption for different station spacings for each class of engine, assuming a level gradient. The fuel consumption per kilometre declines with increasing distance between stops We have assumed a station spacing of 10 miles for local trains, and 20 miles for faster trains (see Table 5). Note, the data only includes fuel consumption, and so it has been necessary to estimate emissions from fuel use.
3. For newer stock, e.g. Virgin Voyager Class 220/221, we contacted the manufacturers directly. However, care should be taken with the figures supplied as they are not generally directly comparable. In general, newer trains consume more fuel as they are much heavier due to improved crash-worthiness. Also the trend is for newer trains to be faster, and therefore more energy is required to overcome the increased air resistance. Again, emissions for these trains have been extrapolated from fuel use.

Table 5. Estimated gas oil use for different train types at the distance between the stops shown (g/km)

Train type	Formation	Unit type	Max. speed	Train type	Station spacing	Fuel (kg/km)
Class 101	1PC + 1TC	DMMU	70mph		16 km	0.83
Class 116	2PC + 0TC	DMMU	70 mph		32 km	0.77
Class 117	2PC + 1TC	DMMU	70 mph		16 km	1.07
Class 121	1PC + 0TC	DMMU	70 mph		16 km	0.50
Class 122	1PC + 0TC	DMMU	70 mph		32 km	0.55
Class 141/1	2PC + 0TC	DHMU	75 mph	Pacer	16 km	0.66
Class 143/6	2PC + 0TC	DHMU	75 mph	Pacer	16 km	0.64
Class 144	2PC + 0TC	DHMU	75 mph	Pacer	16 km	0.59
Class 144	3PC + 0TC	DHMU	75 mph	Pacer	16 km	0.83
Class 150	3PC + 0TC	DHMU	75 mph	Sprinter	16 km	1.02
Class 153/0	1PC + 0TC	DHMU	75 mph	Sprinter	16 km	0.45
Class 156	2PC + 0TC	DHMU	75 mph	Super Sprinter	32 km	0.71
Class 156	3PC + 0TC	DHMU	75 mph	Super Sprinter	32 km	0.92
Class 158/0	2PC + 0TC	DHMU	90 mph	Express	32 km	0.89
Class 158/0	3PC + 0TC	DHMU	90 mph	Express	32 km	1.18
Class 159	3PC + 0TC	DHMU	90 mph	Express	32 km	1.18
Class 165	2PC + 0TC	DHMU	75 mph	Network turbo	32 km	0.58
Class 165	3PC + 0TC	DHMU	90 mph	Network turbo	32 km	0.95
Class 166/0	3PC + 0TC	DHMU	90 mph	Network express turbo	32 km	0.95

Source: Data taken from studies done by AEA Technology Rail, Derby.

Notes: DMMU = diesel Multiple Unit, DHMU = diesel hydraulic multiple unit, PC = power car, TC = Trailer car.

In using the above data, to provide a full set of emissions by train class (with the exception of the LRC data), a two stage approach has been taken.

Fuel consumption data has been used directly to estimate emissions of carbon dioxide and sulphur dioxide emissions, as these are proportional to gas oil consumption. The sulphur content of gas oil is controlled by the "Sulphur Content of Liquid Fuels" Directive. This limited the sulphur content of gas oil to 0.2% by July 2001 and to 0.1% by January 2008. Sulphur dioxide emission factor estimates from trains have therefore been substantially revised since the SRA's Environmental Agenda Report (AEA Technology Environment, 2001).

It is more difficult to estimate emissions of CO, NO_x, PM₁₀ and VOCs, as no direct relationship occur. We have used typical ratios of these pollutants to fuel consumption to derive the factors. Emission ratios for NO_x and CO were taken from the MEET report (Jorgensen & Sorenson, 1997) – a European study which analysed many emission studies for trains across Europe. Although results also covered other pollutants, a meaningful relationship was found only for NO_x and CO. For PM₁₀ and VOCs, we used the average ratios of these pollutants to fuel consumption from the London Research Centre data for diesel locomotives. Emission factors are summarised in Table 6.

Table 6. Estimated emission factors for different diesel train types (g/km)

Train type	CO ₂	SO ₂	VOCs	CO	PM ₁₀	NO _x
Class 37	11270	14.3	12.1	24.5	5.1	51.8
Class 47	16723	21.3	30.8	26.1	5.1	80.1
Class 56	21441	27.3	21.6	43.2	5.1	129.6
Class 58	21441	27.3	11.6	22.5	5.1	103.5
Class 60	20154	25.7	10.4	21.6	4.7	129.6
Class 66	19147	24.4	17.3	6.8	2.9	120.0
Class 67	9277	11.8	10.6	3.8	1.6	66.7
Class 47+7 passenger coaches	9764	12.4	11.1	39.9	5.1	127.6
Class 101 (1PC + 1TC)	2606	3.3	2.5	2.6	0.9	26.5
Class 116 (2PC + 0TC)	2420	3.1	2.3	2.4	0.8	24.6
Class 117 (2PC + 1TC)	3351	4.3	3.2	3.4	1.1	34.1
Class 121 (1PC + 0TC)	1564	2.0	1.5	1.6	0.5	15.9
Class 122 (1PC + 0TC)	1713	2.2	1.7	1.7	0.6	17.4
IC125 (2PC)	12170	31.0	29.1	56.2	17.0	194.8
Class 141/1 (2PC + 0TC)	2085	2.7	2.0	2.1	0.7	21.2
Class 143/6 (2PC + 0TC)	2011	2.6	1.9	2.0	0.7	20.5
Class 144 (2PC + 0TC)	1862	2.4	1.8	1.9	0.6	18.9
Class 144 (3PC + 0TC)	2606	3.3	2.5	2.6	0.9	26.5
Class 150 (3PC + 0TC)	3202	4.1	3.1	3.2	1.1	32.6
Class 153/0 (1PC + 0TC)	1415	1.8	1.4	1.4	0.5	14.4
Class 156 (2PC + 0TC)	2234	2.8	2.2	2.2	0.7	22.7
Class 156 (3PC + 0TC)	2904	3.7	2.8	2.9	1.0	29.5
Class 158/0 (2PC + 0TC)	2793	3.6	2.7	2.8	0.9	28.4
Class 158/0 (3PC + 0TC)	3723	4.7	3.6	3.7	1.2	37.9
Class 159/0 (3PC + 0TC)	3723	4.7	3.6	3.7	1.2	37.9
Class 165 (2PC + 0TC)	1824	2.3	1.8	1.8	0.6	18.6
Class 165 (3PC + 0TC)	2979	3.8	2.9	3.0	1.0	30.3
Class 166/0 (3PC + 0TC)	2979	3.8	2.9	3.0	1.0	30.3
Class 221 (1PC + 3TC)	2594	3.3	2.5	8.2	0.9	26.8
Siemens future diesel 3 car unit	5570	7.1	5.4	5.6	1.8	56.7

Note: The figures in the above table for the Class 100 trains are based on the station spacing shown in Table 4 above.

Electric trains

To estimate emissions attributable to electric traction, we use emission factors for the average UK electricity mix. These emission factors are determined by both the fuel mix and the generating technology used. The emission factors have generally declined over the last 20 years, as older coal and oil fired steam cycle power plants have been replaced firstly by nuclear power stations and more recently by combined cycle gas turbine (CCGT) plants.

Clearly the future emissions associated with electric traction in the railway industry will depend on the electricity generating mix. A number of scenarios are considered here. Our two main scenarios are based on the DTI's own modelling of future energy use, in the EP68 paper. These are the "Central High" (CH) and "Central Low" (CL) scenarios, which refer to a central estimate of GDP growth

coupled with high and low energy prices respectively. Both scenarios anticipate a continued replacement of coal plants by CCGT plants, but this is more marked in the CL scenario, in which coal declines to 6% of the generating mix (as gas grows to 75%) by 2020. Both scenarios indicate a decline in nuclear generation and a steady growth in renewable electricity to 2020, to meet the government's commitment to generate 10% of the UK's electricity from renewable sources by 2010. We have also considered a further sensitivity scenario of higher renewables, in which an indicative target suggested by a recent Performance Innovation Unit (PIU) report of 20% of electricity from renewable sources by 2020 is met. We have assumed that the extra renewable capacity replaces gas. the estimated ESI emission factors are shown in Table 7.

Emissions from electric trains were calculated by multiplying the electricity supply industry (ESI) emission factors by the estimated electricity consumption per kilometre for each train type. As with diesel engines, care must be taken to ensure that estimates are on a comparable basis. Most of our data was obtained from AEA Technology Rail. For some classes, actual measured electricity consumption was available for several different UK journeys, and we have taken the average of the available data. For other classes, we have used theoretical data for flat journeys at an assumed station spacing as shown in Table 8. Data for newer train types was obtained direct from the manufacturers and may not be on a strictly comparable basis.

Table 7. ESI Emission Factors

DTI EP68 Central High Scenario

kt/TWh	2000	2005	2010	2015	2020
CO ₂	523.30	415.74	401.57	413.55	387.95
SO ₂	2.80	0.78	0.55	0.43	0.25
NO _x	1.22	0.85	0.72	0.67	0.55
PM ₁₀	0.08	0.02	0.02	0.02	0.01
VOCs	0.03	0.02	0.02	0.02	0.03
CO	0.20	0.11	0.10	0.09	0.08

DTI EP68 Central Low Scenario

kt/TWh	2000	2005	2010	2015	2020
CO ₂	523.30	369.58	351.69	367.44	370.00
SO ₂	2.80	0.52	0.38	0.20	0.14
NO _x	1.22	0.58	0.47	0.44	0.41
PM ₁₀	0.08	0.01	0.00	0.00	0.00
VOCs	0.03	0.03	0.03	0.03	0.03
CO	0.20	0.12	0.11	0.10	0.10

PIU High Renewables Scenario

kt/TWh	2000	2005	2010	2015	2020
CO ₂	523.30	369.58	351.69	343.91	333.32
SO ₂	2.80	0.52	0.38	0.20	0.14
NO _x	1.22	0.58	0.47	0.44	0.41
PM ₁₀	0.08	0.01	0.00	0.00	0.00
VOCs	0.03	0.03	0.03	0.03	0.03
CO	0.20	0.12	0.11	0.10	0.09

Table 8. Estimated fuel consumption for electric trains (kWh/mile)

Train type	KWh/mile	Source
Class 325 4 car 185 t	8.83	Real journey Tonbridge-Willesden
Class 325 8 car 350t	16.25	Average of real journeys
Class 325 12 car 555t	22.47	Average of real journeys
Class 90 180t	17.3	Average of real journeys
Class 90 500t	22.62	Average of real journeys
Class 90 750t	23.72	Average of real journeys
Class 90 900t	39.68	Average of real journeys
Class 92 1500t	41.48	Average of real journeys
Class 92 750t	21.82	Average of real journeys
Class 92 850t	27.98	Average of real journeys
Class 86 1200t	49.28	Average of 3 real journeys from Crewe
Class 313/0 (2PC+ 1TC)	9.5	Theoretical flat, 3.5 mile station spacing
Class 314 3 car	10	Average of 3 Scotrail journeys, av. 3.5 mile spacing
Class 318 3 car	14.4	Average of 4 Scotrail journeys, av 2 mile spacing
Class 319 (1PC+ 2TC)	13.7	Theoretical flat, 3.5 mile station spacing
Class 321/322 (1PC+3TC)	9.4	Theoretical flat, 3.5 mile station spacing
Class 323	10.5	Theoretical flat, 3.5 mile station spacing
Class 332	21.3	Real journey Paddington-Heathrow
Class 333 3 car	23	Average of 6 real journeys Leeds-Bradford area
Class 333 4 car	24	Average of 6 real journeys Leeds-Bradford area
Class 334 3 car	15.6	Average of 6 real Scotrail journeys
Class 350 4 car	105.6	Average of real journeys
Class 357 4 car	16.5	Average of 3 real journeys out of Fenchurch St
Class 365 (2MC+2TC)	15	Assumed slightly less than class 357
Class 373 18 car	32.3	Average of real journeys
Class 375		Being sought from manufacturer
Class 390 9 car	29	Average of 14 real intercity journeys from London Euston
Class 411 (2MC+1TC)	6.7	Theoretical flat, 15 mile station spacing
Class 421 (1MC+3TC)	8.7	Theoretical flat, 15 mile station spacing
Class 423 (1MC+3TC)	7.2	Theoretical flat, 15 mile station spacing
Class 442 (1MC+4TC)	13.3	Theoretical flat, 15 mile station spacing
Class 455 (1MC+3TC)	7.8	Theoretical flat, 10 mile station spacing
Class 456 (1MC+1TC)	5.7	Theoretical flat, 3.5 mile station spacing
Class 458		Being sought from manufacturer
Class 460 8 car	26.8	Average of 4 real journeys Victoria-Gatwick
Class 465 (2MC+2TC)	11.0	Theoretical flat, 10 mile station spacing
Class 507 (2MC+1TC)	9.14	Theoretical flat, 3.5 mile station spacing

Source: AEAT Rail, Derby
MC=motor car, TC=trailer car

Road emission factors

In November 2001, a new set of emission factors from road transport was released by DEFRA (Department for Environment, Food and Rural Affairs). These were derived from a review and assessment of the new set of speed-emission coefficients reported by TRL from their analysis of new emission test results on vehicles meeting mainly Euro I and II standards. Details of the vehicles tested

and the results obtained are provided in the TRL Report by Barlow, Hickman and Boulter. These new emission factors are provided in the spreadsheet produced with this report for SRA. The adoption of the new road transport emission factors has led to a predicted increase in nitrogen dioxide emissions from road transport in the future.

The emissions in the spreadsheet includes the new emission factors for individual vehicles based on the revised test data.

The data has also been used to look at the average fleet emissions from passenger and freight road transport. To derive these values, we have used Government predictions from the National Road Traffic Forecast (NRTF) model of vehicle fleet composition in future years. This makes assumptions in terms of the fraction of diesel and petrol vehicles on the roads and in terms of the fraction of vehicles on the road made to the different emission regulations which applied when the vehicle was first registered (Euro I, II, III etc). In addition the decrease in vehicle kilometres travelled with increasing age of the vehicle is taken into account.

The values presented are 'Hot' exhaust emission factors. These are dependent on average vehicle speed and therefore the type of road the vehicle is travelling on. Emission factors for urban, rural and motorway road types are provided for every year from 2000 to 2025 for petrol and diesel cars, petrol and diesel light good vehicles (LGVs), rigid and articulated heavy good vehicles (HGVs), buses and coaches and motorcycles. The following pollutants are covered: CO₂, SO₂, NO_x, CO, VOCs & PM₁₀. We have not included 'cold start' emissions, emissions of particulates from tyres and brakes, or fugitive emissions of VOCs. This is firstly because these categories of emission are not available for trains, and also because additional assumptions about journey length etc. would be required which are outside the scope of this study.

As well as estimating emissions per km for typical urban, rural and motorway driving, there are formulae for calculating emissions at specific speeds using a set of coefficients derived by fitting curves to measured emission data. Although these emission factors have been derived from measured tests on real vehicles, and represent the best data available today, there are some as yet unexplained features in the emission profiles. The main one is that the CO₂ emissions from HGVs exhibit an unusual pattern when going from pre-Euro to Euro 1 and 2 vehicles. Also, it should be noted that the speed-dependent estimates for CO₂ and SO₂ emissions from Euro 3 and Euro 4 vehicles do not take account of any future improvements in fuel efficiency for these Euro categories – this means that speed dependent emissions of CO₂ and SO₂ from cars in future years may be slight over-estimates.

The emission factors for urban, rural and motorway driving are listed in Tables 9 to 14.

The road and rail emissions model

A simple spreadsheet model has been developed which enables the user to calculate the net emissions from enhancements to rail services, taking account of displaced emissions from road travel.

There is a choice of two worksheets:

1. **Strategic Plan.** This allows the user to enter changes to distance travelled for all the main engine types currently operating.
2. **Scheme Enhancement.** This allows the user to enter details of a single enhancement scheme in which one engine type increases its distance travelled and one engine type reduces its distance travelled.

In both cases, the user may enter details of the road transport which is displaced by the scheme. As a single rail journey may displace more than one mode of transport, the user is permitted to enter displacement for all vehicle types and for three different journey types: urban, rural and motorway. For example, a freight train journey may displace both urban delivery van travel and motorway and rural HGV travel. Similarly a passenger train journey may displace both car and bus transport, on urban, rural and motorway roads.

For freight transport (both road and rail), distances are entered in tonne-kilometres (or tonne-miles), and the average payload of each train type must also be entered. For passenger transport, distances are entered in kilometres or miles. The user may select whether distances are to be based on kilometres or miles in a dropdown box at the top of each worksheet.

As an alternative to entering transport of urban, rural and motorway routes, the user may enter a specific speed at which road vehicle emissions are to be calculated. Distances for up to three specific speeds may be entered (as travel on more than one type of route may be displaced). To enter data at specific speeds, simply click on the "speed specific" check box next to each block of road travel data. To revert to urban / rural / motorway speeds, de-select the check box.

The user also has the choice of entering data for petrol and diesel cars separately, or entering data for all cars together, in which case emissions are calculated assuming the national mix of diesel and petrol cars. To select this option, click on the "petrol/diesel car" check box adjacent to each block of road travel data. If this box is checked, separate rows will appear for petrol and diesel cars.

For electric trains, emissions depend on the electricity generation mix, which varies depending on the future scenario chosen and on the year. The user selects the year and scenario in a dropdown box at the top of each worksheet. Scenarios are described above (pages 10-11). The Central High scenario is often taken as the default option. The year of analysis also affects the road transport emissions, which change as newer vehicles enter the UK fleet. Finally, it determines the sulphur emissions from trains, as the sulphur in fuel directive coming into force in 2008 reduces the sulphur content of diesel fuel from 2% to 1%.

Our estimated emission factors for trains are all specific to a certain configuration of train, in terms of the number of locomotives, number of power cars and number of trailer cars. All locomotive-hauled trains have a single locomotive except for Class 43 Intercity 125 trains which have two locomotives, one at each end. DMUs have the configurations indicated in the train class name (e.g. 1PC + 1TC is one power car plus one trailer car). Electric freight trains are listed at various loads (e.g. the class 90 is listed at 180t, 500t, 750t and 900t) – the user should select the nearest load. The model could be improved by offering the facility to scale the electricity consumption by the load, so that a specific load could be entered for each freight train. However, this was outside the scope of the present project.

After entering all data, the user should press the “calculate” button adjacent to the results box to view the net emissions from road and rail vehicles. Note that this button is only needed when the user has entered speed-specific data for road vehicles – otherwise the results feed through automatically to the results boxes.

Data sources and limitations

We have taken care to ensure that the best available data has been gathered for this model. However, there is a general lack of up to date and rigorous data for emissions from trains in the UK. As mentioned throughout the text, care must be taken when applying the emission factors. Below we summarise all our data sources plus the caveats applying to the data provided in this report.

1. For older diesel locomotives (non-DMU), emissions for locomotives are based on the 1998 LRC study. All emissions assume one locomotive per train except for the Intercity 125 where two locomotives are assumed. All emissions are per train, not per locomotive.
2. For DMUs and some EMUs (classes 313, 319, 321, 323, 411, 421, 423, 442, 455, 456), emissions are derived from theoretical calculations for flat journeys, assuming a station spacing depending on train type (see Tables 6 and 8). Actual emissions will vary from these estimates depending on the gradient, speed, train loading and (particularly) station spacing. Emissions are only available for specific configurations of DMU or EMU, i.e. numbers of power and trailer cars, as listed in the tables.
3. For Intercity 125 trains, there is some uncertainty over the CO₂ emissions factor. The present value should be regarded as a rough estimate. Further work is required to refine the value.
4. For diesel engines, emissions for pollutants other than CO₂ and SO₂ have been derived from the average ratio of these pollutants to fuel consumption in published sources (the MEET report for NO_x and CO, the LRC data for PM₁₀ and VOCs). These estimates are only approximate and do not take account of differences between engine technologies.
5. For newer trains, estimates of fuel consumption have been obtained direct from manufacturers and may not be on a comparable basis to the estimates for older trains.
6. For some electric trains (Class 314, 318, 332, 333, 334, 350, 357, 373, 390), estimates are derived from measured real electricity consumption over several different journeys in the UK for each class of engine. These estimates therefore take account of gradients on the journeys. However, as data is only available for 3 or 4 different journeys for each engine class, this does not represent a UK-wide average. Individual journeys will of course have different electricity consumptions depending on gradients and station spacing etc.
7. For freight trains, data is only available at a certain range of loads, or in some cases for an “average” load which is not defined. Note, average loads will not be the same (i.e. the average load for a class 66 and class 67 will be dramatically different, reflecting their typical usage). In all cases, different loads will have different fuel consumption and therefore different emissions.
8. For road transport, there are some unexplained features to the speed-dependent data for CO₂ emissions from HGVs. Also, speed-dependent CO₂ data for all vehicle types does not take account of any future improvements to fuel efficiency for Euro 3 and 4 vehicles.

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LRC, 1998, London Research Centre, UK Emission Factor Database.

National Atmospheric Emissions Database (NAEI), 2001, www.naei.org.uk.

Table 9: CO2 Emission factors for road vehicles

Carbon	g/km	2000	2005	2010
Petrol cars	Urban	184.68	174.46	164.28
	Rural	155.08	146.49	137.95
	Highway	214.72	202.83	190.99
Diesel cars	Urban	145.42	135.09	124.85
	Rural	104.06	96.67	89.34
	Highway	125.30	116.40	107.57
Petrol LGVs	Urban	253.13	240.73	228.94
	Rural	199.45	189.69	180.39
	Highway	286.31	272.30	258.95
Diesel LGVs	Urban	284.32	270.40	257.15
	Rural	254.95	242.46	230.58
	Highway	359.02	341.44	324.71
Rigid HGVs	Urban	566.73	538.10	511.42
	Rural	523.41	496.97	472.33
	Highway	609.08	578.31	549.63
Artic HGVs	Urban	1227.67	1165.66	1107.85
	Rural	1007.71	956.81	909.36
	Highway	1073.63	1019.40	968.85
Buses & coaches	Urban	1399.89	1373.96	1348.02
	Rural	684.43	671.75	659.07
	Highway	693.66	680.81	667.96
Motorcycles	Urban	125.69	125.69	125.69
	Rural	138.65	138.65	138.65
	Highway	173.76	173.76	173.76

Table 10: SO₂ Emission factors for road vehicles

Sulphur	g/km	2000	2005	2010
Petrol cars	Urban	0.0130	0.0056	0.0052
	Rural	0.0109	0.0047	0.0044
	Highway	0.0151	0.0065	0.0061
Diesel cars	Urban	0.0037	0.0034	0.0032
	Rural	0.0026	0.0025	0.0023
	Highway	0.0032	0.0030	0.0027
Petrol LGVs	Urban	0.0178	0.0077	0.0073
	Rural	0.0140	0.0061	0.0058
	Highway	0.0201	0.0087	0.0083
Diesel LGVs	Urban	0.0072	0.0069	0.0065
	Rural	0.0065	0.0062	0.0059
	Highway	0.0091	0.0087	0.0083
Rigid HGVs	Urban	0.0144	0.0137	0.0130
	Rural	0.0133	0.0127	0.0120
	Highway	0.0155	0.0147	0.0140
Artic HGVs	Urban	0.0313	0.0297	0.0282
	Rural	0.0257	0.0244	0.0232
	Highway	0.0273	0.0260	0.0247
Buses & coaches	Urban	0.0356	0.0350	0.0343
	Rural	0.0174	0.0171	0.0168
	Highway	0.0177	0.0173	0.0170
Motorcycles	Urban	0.0088	0.0040	0.0040
	Rural	0.0097	0.0044	0.0044
	Highway	0.0122	0.0055	0.0055

Table 11: NOx Emission factors for road vehicles

NOx	g/km	2000	2005	2010
Petrol cars	Urban	0.69	0.34	0.22
	Rural	0.91	0.42	0.26
	Highway	1.36	0.64	0.39
Diesel cars	Urban	0.55	0.55	0.38
	Rural	0.50	0.50	0.35
	Highway	0.76	0.79	0.57
Petrol LGVs	Urban	1.05	0.37	0.15
	Rural	1.21	0.43	0.18
	Highway	1.62	0.60	0.26
Diesel LGVs	Urban	1.07	0.88	0.57
	Rural	0.95	0.76	0.49
	Highway	1.38	1.16	0.76
Rigid HGVs	Urban	6.97	5.26	3.59
	Rural	6.64	4.93	3.31
	Highway	7.00	5.15	3.44
Artic HGVs	Urban	15.04	10.98	7.14
	Rural	14.04	10.28	6.54
	Highway	14.47	10.69	6.81
Buses & coaches	Urban	11.78	9.12	6.30
	Rural	6.93	5.10	3.47
	Highway	7.12	5.30	3.62
Motorcycles	Urban	0.13	0.14	0.15
	Rural	0.22	0.23	0.24
	Highway	0.40	0.41	0.44

Table 12: PM10 Emission factors for road vehicles

PM10	g/km	2000	2005	2010
Petrol cars	Urban	0.0084	0.0032	0.0021
	Rural	0.0063	0.0030	0.0022
	Highway	0.0102	0.0070	0.0062
Diesel cars	Urban	0.0907	0.0703	0.0359
	Rural	0.0737	0.0545	0.0265
	Highway	0.1104	0.0798	0.0414
Petrol LGVs	Urban	0.0189	0.0048	0.0011
	Rural	0.0158	0.0046	0.0015
	Highway	0.0453	0.0137	0.0053
Diesel LGVs	Urban	0.1559	0.1345	0.0897
	Rural	0.1453	0.1313	0.0867
	Highway	0.2992	0.2694	0.1796
Rigid HGVs	Urban	0.2864	0.1423	0.0735
	Rural	0.2342	0.1155	0.0590
	Highway	0.2309	0.1145	0.0586
Artic HGVs	Urban	0.4708	0.3357	0.1643
	Rural	0.3799	0.2714	0.1313
	Highway	0.3692	0.2692	0.1305
Buses & coaches	Urban	0.4632	0.2397	0.1177
	Rural	0.2262	0.1253	0.0625
	Highway	0.2037	0.1184	0.0614
Motorcycles	Urban	0.0982	0.0982	0.0982
	Rural	0.1101	0.1101	0.1101
	Highway	0.1200	0.1200	0.1200

Table 13: CO Emission factors for road vehicles

Carbon monoxide	g/km	2000	2005	2010
Petrol cars	Urban	4.00	1.99	1.53
	Rural	2.72	1.50	1.19
	Highway	4.88	3.68	3.09
Diesel cars	Urban	0.35	0.23	0.16
	Rural	0.21	0.13	0.09
	Highway	0.24	0.16	0.11
Petrol LGVs	Urban	9.43	3.35	1.75
	Rural	5.78	1.90	0.90
	Highway	20.86	6.30	2.60
Diesel LGVs	Urban	0.71	0.49	0.34
	Rural	0.51	0.34	0.24
	Highway	0.72	0.46	0.32
Rigid HGVs	Urban	2.05	1.40	1.40
	Rural	1.45	1.09	1.06
	Highway	1.29	0.92	0.89
Artic HGVs	Urban	1.71	1.31	1.34
	Rural	1.38	1.14	1.14
	Highway	1.25	1.04	1.04
Buses & coaches	Urban	5.58	3.23	2.72
	Rural	2.23	1.21	0.92
	Highway	1.29	0.87	0.75
Motorcycles	Urban	18.55	14.49	9.73
	Rural	20.36	17.31	13.72
	Highway	28.29	24.89	20.90

Table 14: VOC Emission factors for road vehicles

VOCs	g/km	2000	2005	2010
Petrol cars	Urban	0.521	0.198	0.140
	Rural	0.321	0.121	0.085
	Highway	0.303	0.131	0.096
Diesel cars	Urban	0.059	0.038	0.025
	Rural	0.029	0.018	0.012
	Highway	0.017	0.010	0.006
Petrol LGVs	Urban	1.055	0.242	0.041
	Rural	0.487	0.127	0.036
	Highway	0.678	0.194	0.070
Diesel LGVs	Urban	0.200	0.144	0.100
	Rural	0.114	0.084	0.059
	Highway	0.097	0.065	0.044
Rigid HGVs	Urban	1.643	0.976	0.668
	Rural	1.068	0.672	0.449
	Highway	0.958	0.540	0.357
Artic HGVs	Urban	1.130	0.840	0.543
	Rural	0.766	0.606	0.384
	Highway	0.644	0.493	0.312
Buses & coaches	Urban	1.675	1.254	0.943
	Rural	0.877	0.591	0.385
	Highway	0.744	0.480	0.304
Motorcycles	Urban	3.849	3.112	2.247
	Rural	1.941	1.678	1.369
	Highway	1.075	0.834	0.552